THE INFLUENCE OF ENVIRONMENTAL AND BODY-BASED ACTION CONSTRAINTS ON DISTANCE JUDGMENTS

by

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ABSTRACT

To determine action capabilities, an actor must take into account environmental features and the actor's individual body and capabilities. Previous research has shown that changing an actor's ability to reach by changing the *body* influences judgments of distance to reachable objects. The current studies tested whether both *environmental* and body constraints that limit reaching would influence judged distances to reachable objects. In Experiment 1, participants estimated distances to a small object when it was both in front of and behind a clear, reach-limiting Plexiglas barrier. Participants estimated their ability to reach the object (yes or no response), and then visually matched the distance from the edge of the table to the object with a tape measure. Participants judged the distance to the object as farther when the object was behind the barrier than when it was in front of the barrier; the barrier also reduced estimates of reach ability. In Experiment 2 participants estimated distances in front of and behind a barrier while their dominant or non-dominant hand was weighted, a body constraint on action. Distances within reachable space were judged to be significantly farther than the other conditions when the target was behind the barrier and the dominant (reaching) hand was weighted. This study suggests that action-relevant environmental constraints do influence judgment of distances and interact with body-based constraints.

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

Traditional approaches to understanding space perception emphasize the use of visual information in discovering the geometry of the environment. Though this approach has yielded years of important research in space perception, recent work has highlighted an influence of nonvisual information (specifically, body capabilities) on judgments of space. For example, if an observer is holding a baton that changes her ability by extending her reach, she judges reachable objects as closer (Witt, Proffitt, & Epstein, 2005). Thus, a change in ability qualifies as nonvisual information that may contribute to the perceived layout of the environment. However, the environment itself could also have an effect on an observer's capability to act. If one is sitting behind a window, such as at a ticket booth, the ability to reach is altered due to an environmental parameter rather than a change to the body or changes in visual information. In the current studies, we test how constraints on action due to the environment influence the perception of reachable space. In addition, we investigate whether constraints in the environment combined with body-based constraints result in even further changes to the perception of reachable space.

The idea that both the environment and the body can affect space perception is not new. Gibson (1979) proposed that observers view the environment based on both of these aspects. He used the term affordances to describe the actions allowed a particular observer by a particular environment. Observers with different bodies may view the same environmental features based on what actions those features allow for their body. For example, a basketball player would see a tall shelf as reachable whereas a child may not, due to their difference in height.

While bodies may be different, the environment can be parsed into distinct areas that may also be perceived differently. Cutting and Vishton (1995) proposed that personal space (also called near or peripersonal space) is the space within arm's reach and slightly beyond, whereas action space (also called far or extrapersonal space) is the space of an individual's public action (e.g., speaking, throwing, or brief walking). They also defined vista space as space that is beyond such action (about 30 m). Cutting and Vishton suggested that different visual cues are used within these different action spaces (e.g., accommodation and convergence for near space and height in the plane for vista space), though some work does suggest there are situations in which cues can be used across types of space (Medendorp & Crawford, 2002). In addition to the use of different visual cues for different spaces, neurological evidence shows different brain activity when a target is in near space vs. far space (Cardellicchio, Sinigaglia, & Costantini, 2011; Weiss, Marshall, Zilles, & Fink, 2003). Since these space boundaries are defined in terms of action, they are not static but plastic and can change based on a person's abilities (Lourenco & Longo, 2009; Berti & Frassinetti, 2000; Longo & Lourenco, 2006) and may gradually transition from near to far space (Longo & Lourenco, 2006). For the purposes of this article we will consider "near space" to be the space within or close to within reach and "far space" to be the space outside of reach.

Traditional Distance Measures

Though people may perceive space differently based on these near and far delineations, the measurement of each is similar. The traditional measures of both near and far space are verbal report and magnitude estimation. Verbal report is simply an estimate of a distance in units such as feet or meters. Verbal reports are usually fairly accurate at near distances but become underestimated as target distance increases (Loomis & Philbeck, 2008). Magnitude estimations are a subset of verbal estimates. A participant may report an extent in commonly used units such as inches or meters, or may use an operationally defined unit of measure. In another measure, a matched estimate, the participant matches a target distance to another distance. For example, to get an estimate of the height of a building, the participant would match the distance from the ground to the height (target distance) with the horizontal distance from the participant to an experimenter (match distance). For near space measurements a participant may match a target distance with the length of a ruler or length of a line on a computer screen. In addition, participants may be asked to reach to targets in near space, while also reporting the distance to the target either before or after (Pagano & Bingham, 1998). Findings show that verbal reports may be influenced by the performance of actions, such as reaching in near space. Action measures such as blind walking and blind throwing are also measures of distances in far space, and are often considered analogous to blind reaching in near space (Sahm, Creem-Regehr, Thompson, & Willemsen, 2005). To acquire these blind action measures, a participant will view a target, then be blindfolded and walk to the target, throw an object to the target, or reach to a previously seen object.

Affordance Judgments and Space Perception

A more indirect measure of distance for both near and far space is an action-based affordance judgment. For an action to be possible, there must be coordination between the actor and environment (e.g., to walk under an overhang without ducking, the height of the overhang should be greater than the height of the walker; Stefanucci & Geuss, 2010). As a measure, an affordance judgment is a yes-or-no judgment of whether or not an observer can perform a specific action. Previous research has shown that people scale environmental features such as distance to their bodies and body capabilities. For example, wide individuals estimated widths to be passed as smaller than did narrow individuals (Stefanucci & Geuss, 2009). Near space affordance judgments may specify actions such as reaching, grasping, or fitting a hand through an aperture, while far space affordance judgments may specify actions such as walking under a barrier, climbing a hill, or jumping a distance. Affordance judgments in conjunction with magnitude estimation encourage observers to view space in terms of a specific action (Witt, Proffitt, & Epstein, 2004).

Influence of the Body on Distance Perception in Far and Near Space

Far space. Previous research has shown that manipulations of the body that affect the ability to act in “far” space, or spaces beyond the body, can influence perception of that space. One line of research has manipulated the body by varying the behavioral potential of the actor. For example, judgments of distance have been shown to be influenced (scaled) by whether or not the observer is wearing a backpack while he or she makes the judgment (Proffitt, Stefanucci, Banton, & Epstein, 2003). Lessard, Linkenauger, and Proffitt (2009) found that when observers wore ankle weights while estimating whether or not they could jump across a gap, they judged *jumpable* distances to be greater than when they did not wear weights; distances outside of a participant’s jumping ability were not scaled as the intended action was not relevant to that space. It is important to note, however, that other explanations for changes in distance judgments that do not focus on body-based changes have been proposed, such as task demands (Durgin, Baird, Greenburg, Russell, Shaughnessy, & Waymouth, 2009; Woods, Philbeck, & Danoff, 2009). Further research has manipulated not only the ability to act, but the intention to act, in the context of distance judgments. When an observer intends to walk to an extent, they perceive a distance to be longer when effort associated with walking is increased. If the effort associated with walking, however, is increased and they intend to throw to the distance rather than walk to it, the perceived distance is unchanged (Witt, Proffitt, & Epstein, 2004). Extents are scaled only when the effort to act within that space is changed. Throwing was not limited so the extent to be thrown was not scaled, but walking ability was made more effortful, so the extent to be walked was scaled. Extending beyond effort are studies of individual differences of the body such as those with chronic pain. Chronic pain patients judged distances to be walked as farther than individuals without chronic pain who were age-matched controls (Witt, Linkenauger, Bakdash, Augustyn, Cook, & Proffitt, 2009). Manipulating actual body dimensions has also been shown to change judgments of space. Using virtual environments, van der Hoort, Guterstam, and Ehrsson (2011) changed virtual body size of a self-avatar and found that objects appeared both larger and farther away when participants experienced a tiny body. Likewise, when participants experienced a giant body, objects appeared smaller and closer. Related work that changed body dimensions in the real world also showed an influence on the scale of perceived space. For example, Stefanucci and colleagues found that individuals who are wider (broader of shoulder) perceive apertures to be smaller, and those who are taller perceive horizontal barriers as shorter (Stefanucci & Geuss, 2009; 2010).

Near space. Ample evidence collected from studies using a variety of measures shows that dimensions of and changes to the body affect perceived distance and reachability in near space. Witt et al. (2005) found that when an observer's ability to reach had been enhanced (due to holding a baton), the perceived distance to targets was estimated to be shorter (but see, de Grave, Brenner, & Smeets, 2011). Linkenauger, Witt, Stefanucci, Bakdash, and

Proffitt (2009) found that difficulty associated with grasping an object increased the perceived distance to that object for right-handed observers. Balcetis and Dunning (2010) showed that when participants were motivated to obtain more desirable objects (e.g., money they could win), those objects appeared closer than less desirable objects. In contrast, when the ability to reach is decreased through constriction of degrees of freedom for reaching (Carello, Grosofsky, Reichel, Solomon, & Turvey, 1989) or by wearing arm weights (Rochat & Wraga, 1997) observers retune their perceived boundary for reaching (or the farthest extent that a person could reach). Similarly, adding arm weights to participants who performed a line bisection task in near space decreased their perceived boundary of near space (Longo & Lourenco, 2007). Ambrosini, Sinigaglia, and Costantini (2011) found that eye movements to an action-related target are altered when the body is constricted (e.g., unable to reach because the arms are tied), suggesting a potential attentional mechanism that may underlie the previously mentioned perceptual effects.

Influence of the Environment on Distance Perception in Far and Near Space

Far space. While less research has tested constraints of the environment on space perception, several studies do suggest that environmental constraints affect perceptions of far space. Though Jiang and Mark (1994) examined the effect of gap depth on perception of gap crossability (not distance perception directly), they found that when a gap was deep, participants judged the gap to be less crossable than when the gap was shallow, even though the distance across the gaps was equivalent. These findings suggest that an environmental parameter, such as the depth of the gap, while not important for determining one's ability to cross the gap, had an effect on perceived gap width. In a more direct test of distance perception, Stefanucci, Proffitt, Banton, and Epstein (2005) showed that distances were perceived to be farther when displayed on a hill as compared to the same distance displayed on a flat ground plane. Again, a difference in the environment affected perceived distance in that environment. Witt, Stefanucci, Riener, and Proffitt (2007) also examined the effect of changes in the environment on the perception of ground plane distances. They found the perceived distance to targets in a hallway (measured with a visual matching task or with blindwalking) was influenced by the length of the hallway that extended beyond the target. If the hallway was longer, participants perceived the distance to be closer than when the same distance was shown in a short hallway. While these studies suggest that environmental parameters unrelated to distance can affect perceived distance in far space, the question remains as to whether these parameters will also affect distances in near space. It should be noted that other than Stefanucci et al. (2005), these studies did not set out to manipulate potential to act in their environmental manipulations. There could be visual information or contextual accounts for why the distance estimations were different.

Near space. In the current studies, we investigate the effects of environmental constraints on judgments about action and perceived distances in near space. To our knowledge, only a handful of experiments have examined this influence of the environment prior to the current studies. Cardellicchio, Sinigaglia, and Costantini (2011) found higher motor evoked potentials in the left primary motor cortex when participants observed graspable objects within reachable space compared to nongraspable objects within reachable space or any object outside of reachable space. These results show that aspects of the environment (whether an object is graspable or not) can evoke differential motor potentials. Another study used a barrier to block potential action (Costantini, Ambrosini, Tieri, Sinigaglia, & Committeri, 2010). In an immersive virtual environment, participants saw a left or right hand, viewed an object that was either in front of (reachable) or behind (unreachable) a translucent barrier, and then made a precision grip with the specified hand. Reaction times to the stimulus object were higher when the target was behind the barrier than in front of the barrier if the target was within reachable space, but there was no difference in reaction times when the object was beyond reachable space. With the previous study, this demonstrates additional evidence that possible actions may elicit different neural and action processes than impossible actions. Most recently, Morgado, Gentaz, Guinet, Osiurak, and Palluel-Germain (2012) asked participants to estimate the distance to a cylinder behind a clear barrier of various widths. They found that participants estimated the egocentric distance as greater when the width of the barrier was greater; limiting a relevant action, reaching with the barrier, affected perceived distance for reaching. This study provides evidence in favor of the influence of environmental constraints on space perception, although the absolute affordance did not change; in all cases the target was reachable. Morgado et al. (2012) manipulated the effort to reach the cylinder using different barrier widths but did not eliminate the possibility to act on the cylinder. These studies leave unanswered the question of how environmental constraints and possibilities for action influence perception of the environment. Does changing the action possibilities of the environment influence the perception of extent? How are body-based action capabilities integrated with environment-based action possibilities to make judgments of perceived extent? The proposed experiments test these questions.

Overview of Current Studies

Previous studies provide converging evidence that both environmental and body constraints may influence distance perception in near space. Despite this previous research, it is unclear the extent to which environmental constraints influence perception in near space, and how they interact with body-based constraints. The previous work in near space used methodologies that addressed the influence of environmental constraints on motor system activity or attention, but measures of perceived spatial extents have been examined only in the context of effort. In Experiment 1, we examined whether changing the action possibilities of the environment influence the perception of extent. We obtained action judgments and estimates of distance to a target in the real world when the target was in front of a clear barrier (reachable) and behind the clear barrier (unreachable), using a barrier paradigm similar to Morgado et al. (2012), although the barrier used in the current study was large enough to block reaching entirely. We expected participants to judge reachable distances to be greater when the environment did not allow an observer to reach the target.

In Experiment 2, we investigated whether environmental constraints and body-based constraints would interact to have a unique effect on the perception of distance. We manipulated both the possibility of reaching the target via the environment by using the barrier from Experiment 1 and via the body by weighting the participants' dominant (reaching) or nondominant hand. Lourenco and Longo (2009) used wrist weights to increase the effort involved in performing a line bisection task. The participants showed a bias while wearing the weights that implied that their perception of near space contracted. Their study limited reaching action but did not assess perceived extents. Experiment 2 of this study manipulated reaching via the environment and body, and explicitly measured the perception of reaching-relevant extents. We expected reachable but not unreachable distances to be judged as greater when reaching was limited via either the body or environment compared to when reach was not limited. We expected distances to be judged as even greater when reaching was constrained in two ways than when it was constrained in only one way.

EXPERIMENT 1

The purpose of this experiment was to determine if the action possibilities of the environment influence the perception of extent. We used a barrier, similar to Costantini et al. (2010) and Morgado et al. (2012), in order to limit the possibility of reaching a target. Participants made reachability and distance estimates to a target that was either in front of or behind the clear barrier. While the barrier did not restrict visibility, it did restrict environmental interaction for spaces on the other side of the barrier. Therefore, a participant would be able to reach or interact with the target when it was in front of the barrier, but would not be able to interact with the target when it was behind the barrier. We predicted that limiting the possibility of reaching the target in this manner would result in greater estimates of egocentric distances than when reaching the target was possible. This would imply a contraction of near space when action is constrained by the environment, consistent with previous research showing contraction of near space when the body's capabilities were constrained (e.g., Witt et al. 2005; Lourenco & Longo, 2009).

Method

Participants. Twenty University of Utah undergraduate students (8 males, 12 females) participated for class credit. All participants provided written informed consent and had normal or corrected to normal vision. Eighteen participants were right-handed and two were left-handed.

Stimuli and apparatus. Participants judged their ability to reach a target (3 cm round red plastic disc) and the distance to that target on a table when it was behind or in front of a clear barrier (see Figure 1). The experiment was performed in a laboratory with standard industrial fluorescent lighting. The table was 93 cm square and a tan tablecloth covered it. Participants sat in a chair, the back of which was 50 cm away from the front edge of the table. The barrier was 92 cm tall, 122 cm wide, and made of Optix brand clear acrylic; looking through the barrier is similar to looking through a large clear window. The barrier was centered and level with the table so that the participant could not reach under, above, or around the barrier, differing from the narrower barrier that could be reached around in Morgado, Gentaz, Guinet, Osiurak, and Palluel-Germain (2012). The barrier was placed at a target distance, then the target was placed in front of or behind the barrier. For example, if the barrier was placed at 33.0 cm, the target would be placed either in front of the target at 28.5 cm or behind the target at 34.5 cm depending on the trial condition. The barrier was held in place using a wooden frame.

Design. A within-subjects design was used for condition (in front of barrier and behind barrier) and for target distances (10.1, 17.8, 25.4, 33.0, 40.6, 48.3, 53.3, 61.0, 68.6, and 76.2 cm from front edge of table). Participants saw each distance once in each condition, so performed ten trials with the target in front of the barrier and ten trials with the target behind the barrier for twenty trials total. The order of presentation of trials was randomized.

Procedure. Participants provided informed consent, completed a demographics form, and were verbally briefed on the experimental tasks. The participants were told that they would see an object at different distances and would be asked if they could reach the object with their dominant hand. They were not allowed to lean forward or move out of their chair and could only think about reaching out with their arm while keeping their arms still. They were also told to make sure they kept their hands in their lap at all times. If the participant could reach out with a finger to touch the object, that counted as a successful reach. The participant was then briefed on the distance-matching task and practiced the experimental tasks.

In a given trial, the participant first performed the reachability task. The experimenter asked, “Could you reach the object without leaning.” The participant responded with a yes or no answer. The participant then performed the distance-matching task. The experimenter stood at a right angle to the participant and to the table and pulled out a measuring tape with the blank edge facing the participant. When the participant thought the distance from the edge of the table to the object was the same as the length of the measuring tape, the participant told the experimenter to stop. The participant could then have the experimenter adjust the measuring tape to be longer or shorter until the two distances (tape measure and table-to-target) were as similar as possible. The distance matching task was immediately completed a second time starting with the tape measure as far out as possible (e.g., the arm span of the experimenter). The experimenter shortened the tape measure until the participant told the experimenter to stop. The participant could then instruct the experimenter to make fine adjustments to the length. Participants always reported these two distance estimates for each trial. After the distance-matching task, the participant was told to close his or her eyes while the experimenter measured the next distance and moved the target and barrier.

After the experiment, the experimenter took anthropometric measures, asked the participant questions to assess possible response bias, and debriefed the participant. The anthropometric measures were: handedness, left and right arm length, left and right hand length, distance from the sternum to the edge of the table, and actual longest reach on the table. The response bias questions were: What do you think we were studying today? What do you think was the purpose of the Plexiglas presented on the table? Do you think the Plexiglas affected your judgment of the distance to the target? Do you think the object looked closer, about the same, or farther, when behind the Plexiglas? Did you use any strategies to make your decisions?

Results and Discussion

Participants' mean dominant arm length was 73.65 cm (*SD* = 4.75 cm) and mean actual longest reach was 36.43 cm (*SD* = 8.47 cm). One participant was excluded due to being an outlier two standard deviations above the mean (in the direction of the main effect).

We performed a repeated measures analysis of variance (RMANOVA) with barrier condition (2 levels, in front or behind barrier), measurement (2 levels, first and second), and distance (10 levels) as within subject factors (see Figure 2; error bars in all figures made using Cousineau (2005) method). As predicted, there was a significant main effect for the barrier condition ($F(1, 18) = 18.49$, $p < 0.001$, $\eta^2_p = 0.51$, MSE = 42.74) such that distance judgments were greater when the target was behind the barrier ($M = 51.47$, $SE = 1.21$) than when the target was in front of the barrier ($M = 49.43$, $SE = 1.23$). There was a significant main effect for distance ($F(9, 162) = 533.27$, $p < 0.001$, $\eta^2_p = 0.97$, MSE =91.79) such that distances were reported as farther at greater distances. There was also a significant interaction between the barrier and distance ($F(9, 162) = 2.345$, $p = 0.016$, $\eta^2_p = 0.12$, MSE = 38.89) such that the barrier affected distance judgments more greatly at middle distances (i.e. near the action boundary) than at more extreme high and low distances (see Table 1).

Previous research suggests that manipulating abilities should only affect distance judgments for ability-relevant spaces (Lessard, Linkenauger, & Proffitt, 2009; Witt, Proffitt,

& Epstein, 2005). In this case, changing reaching abilities should influence the perception of reachable spaces, but would not necessarily influence spaces outside of reach. To examine distance judgments across reachable and unreachable spaces, we split each participant's distance judgments based on their actual reach for each condition using the mean of the two measurement trials. For example, if a participant's actual reach was 35 cm, judgments for distances below 35 cm (10.1, 17.8, 25.4, 33.0) would be categorized as "reachable" while judgments for distances greater than 35 cm (40.6, 48.3, 53.3, 61.0, 68.6, 76.2) would be categorized as "unreachable." We then made a ratio for each of the judgments: estimated distance divided by actual distance. By converting the judgments from cm to these ratios, we can compare the effect of the barrier across reachable and unreachable spaces; if we were to compare the cm distance judgments, unreachable distances would obviously be greater than reachable distance judgments. A ratio greater than 1 indicates an overestimation of the distance (e.g., estimate of 11.5 cm / actual distance 10.1 cm = 1.14) while a ratio less than 1 indicates an underestimation of the distance (e.g., estimate of 8.5 cm/ actual distance 10.1 cm = 0.842). We then formed a mean of the ratios for reachable and unreachable distances for each condition (e.g., reachable distances behind the barrier, reachable distances in front of the barrier, unreachable distances behind the barrier, and unreachable distances in front of the barrier.

To test if the variability in distance judgments was different across reachable and unreachable space, we performed a RMANOVA with barrier condition (two levels, in front and behind) and reachable space (two levels, reachable and unreachable) as within-subject factors. There was a significant effect for the barrier condition ($F(1, 18) = 16.76$, $p = 0.001$, $\eta^2_p = 0.48$, MSE = 0.005) such that there was a greater overestimation of distance judgments when the target was behind the barrier (*M* = 1.21, *SE* = 0.030) than when the target was in front of the barrier (*M* = 1.15, *SE* = 0.027, see Figure 2). Note that in both cases distances were overestimated, consistent with other work on estimates of distances within this range (de Grave, Brenner, & Smeets, 2011). While there was not a main effect of reachable distance, the interaction between the barrier condition and reachable distance was marginally significant ($F(1, 18) = 3.31$, $p = 0.086$, $\eta^2_p = 0.16$, MSE = 0.003, see Figure 3). When the target was in front of the barrier, the estimation error of distances in reachable space (*M* = 1.15, *SE* = 0.029) and unreachable space (*M* = 1.14, *SE* = 0.031) was nearly identical. When the target was behind the barrier, the overestimation of distance was greater within reachable space (*M* = 1.24, *SE* = 0.041) than unreachable space (*M* = 1.18, *SE* = 0.029). While not significant, these results indicate a trend that distance overestimates were largest for reachable distances behind the barrier, as the theory and previous results indicate.

To examine the reaching judgments, we found the crossover point between yes and no judgments. This was calculated as the average between the highest consistent (two consecutive) “yes” estimate and lowest consistent (two consecutive) “no” estimate. For example, if a participant judged “yes” at 33.0 cm and “no” at 40.6 cm, the crossover point was calculated as 36.8 cm. The crossover points (estimated reachability) were then divided by a participant’s actual reachability to form a ratio as in the previous analysis. To test these reaching judgments, we performed a paired-sample t-test comparing the crossover point ratios when the target was in front of the barrier (*M* = 1.17, *SD* = 0.22) to the crossover point when the target was behind the barrier (*M* = 1.09, *SD* = 0.21); $t\,(18) = 2.56$, $p = 0.020$ (see Figure 4). There was a significant difference in reaching judgments when the target was in front or behind the barrier; participants estimated their reach as shorter when the target was behind the barrier and inaccessible.

We found the expected difference in the affordance judgments between barrier conditions. Participants judged that they could not reach to distances when the target was behind the barrier that they said they could reach when the target was in front of the barrier (all participants said they could reach at least one distance and could not reach at least one distance). If the effect of the barrier was due to distances appearing farther when the target was behind the barrier, we would expect that this effect could have put some targets out of participants' reach.

In the debriefing, two participants predicted that the purpose of the barrier was to make the target seem farther away. One of these participants said the barrier affected their distance judgments "a little" and one said the barrier did not affect distance judgments. Excluding these participants and repeating the original barrier x measurement trial x distance RMANOVA analyses, there was still a main effect of the barrier ($F(1, 16)=13.48$, $p=.002$, $\eta^2_p=0.46$, MSE=46.75) and distance ($F(9, 144)=466.75$, $p<0.001$, $\eta^2_p=0.97$, MSE=94.54) but the interaction between the barrier and distance was not significant. Two participants predicted that the purpose of the barrier was to change their ability to act (reach or touch). A total of seven participants said that the barrier affected their distance judgments, while six said it affected their distance judgments "somewhat" or "a little." Six participants said that the barrier did not affect their distance judgments. Since only two participants predicted (without prompting) that the barrier was meant to influence judgments and the analyses without those participants indicate an effect of the barrier, we suggest that the influence of experimental demand in this case is low. A majority of participants indicated that the barrier affected their distance judgments when directly asked, but we suggest that the debriefing questions were leading and the participants may not have come to this conclusion without the debriefing. This concern informed the composition of debriefing questions for Experiment 2.

Debriefing results indicated that most people thought the barrier influenced their distance judgments, but only two predicted without prompting that the purpose of the barrier was to influence their distance judgments. While we would like to conclude that there were minimal demand characteristics in this experimental design, we are reluctant to draw definitive conclusions. In particular, the questions: "Do you think the Plexiglas affected your judgment of the distance to the target?" and "Do you think the object looked closer, about the same, or farther, when behind the Plexiglas?" may have suggested to the participants effects that they would not have mentioned on their own.

The results show that when the target was physically inaccessible or "unreachable," due to a location behind the barrier, participants estimated the distance to the target as greater than when the target was in front of the barrier and "reachable." These findings suggest that changing the potential for action in the environment influenced the judgment of distances. However, it is unclear how this interacts with body-based affordances. Since the body was not manipulated, but the environment was, we do not know if or how body and environment based affordances interact. Is one stronger than the other? Does an environmental affordance eliminate the effect of a body-based affordance? Or vice versa? Do they have an additive effect so that distances appear even farther when action is limited by both a body and environmental constraint? Experiment 2 explores this possible interaction.

There were methodological problems with this experiment as well. We discovered after completing the experiment that the experimenter's strategy for target placement was inaccurate. The barrier was placed at the specified distance and the target was placed in front or behind it, rather than placing the target at the specified distance and moving the barrier. Thus, the front of the target was actually +/- 1.5 cm from the specified distance. This 3 cm difference between in front and behind barrier conditions may explain some of the experimental effects. Also, there may have been an effect of memory when performing the two distance match tasks one directly after another. The participant may have estimated the distance on the first distance match then tried to match his or her first estimate on the second estimate. Performing only one measurement per trial will eliminate this possible confound. Third, the space between distances (~7 cm) is not fine enough to show an accurate crossover point between reachable and unreachable distances; the crossover may be within the interstitial space so smaller extents should be used between tested distances. Last, the debriefing questionnaire to check for demand characteristics may have been leading. Participants may have guessed the experimental manipulation and effect based not on their experience within the experiment but based on the wording of the questionnaire. Further experimentation should use more ambiguous wording in order to ascertain a more accurate picture of perceived demand characteristics. Experiment 2 will address these issues.

Table 1

Interaction between Distances and Barrier Condition for Experiment 1

Actual distance	Mean estimated distance in front of barrier	Std. error in front of barrier	Mean estimated distance behind barrier	Std. error behind barrier	Difference in mean estimated distance between conditions (front-behind) *
10.1	12.758	.579	14.037	.572	-1.279
17.8	21.005	.846	21.239	.788	-0.234
25.4	27.238	.798	29.235	.959	-1.997
33.0	35.009	.962	38.534	1.209	-3.525
40.6	44.784	1.400	49.839	2.079	-5.055
48.3	54.627	1.547	58.562	1.868	-3.935
53.3	61.336	1.925	64.093	2.328	-2.757
61.0	70.794	2.086	69.541	2.115	1.253
68.6	78.239	2.480	82.157	2.522	-3.918
76.2	88.541	2.813	87.488	2.111	1.053

*The difference in mean estimated distance (far right column) is the difference between the mean estimated difference for distances in front of the barrier and distances behind the barrier. Differences are greater for middle distances than for high or low distances.

Figure 1. Apparatus used in experiments. Participant sits in front of large clear barrier with small target.

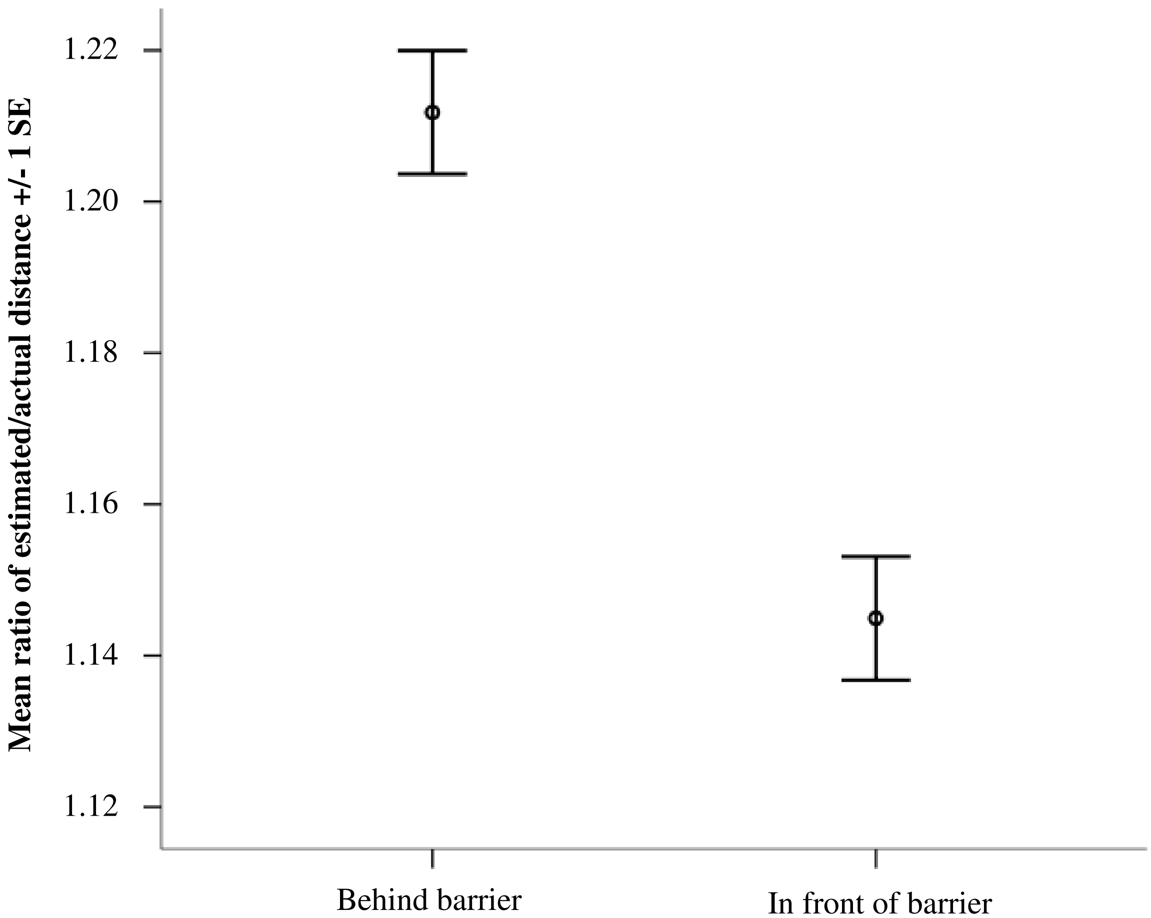

Figure 2. Experiment 1: Mean ratios of estimated distance judgments / actual distances as a function of the barrier conditions. Error bars represent +/- 1 SEM. All error bars were created using Cousineau (2005) method.

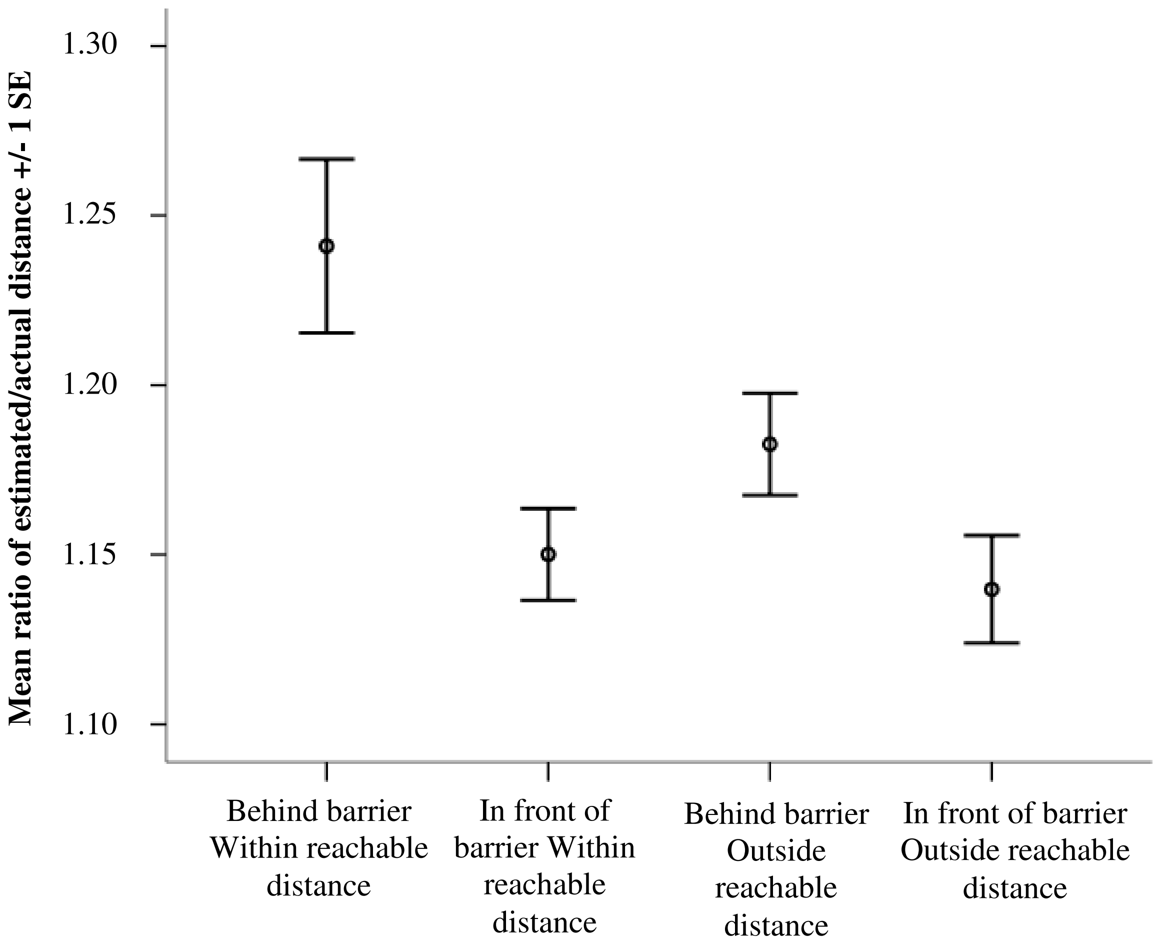

Figure 3. Experiment 1: Mean ratios of estimated distance judgments / actual distances split between reachable and unreachable spaces as a function of the barrier conditions. Error bars represent +/- 1 SEM.

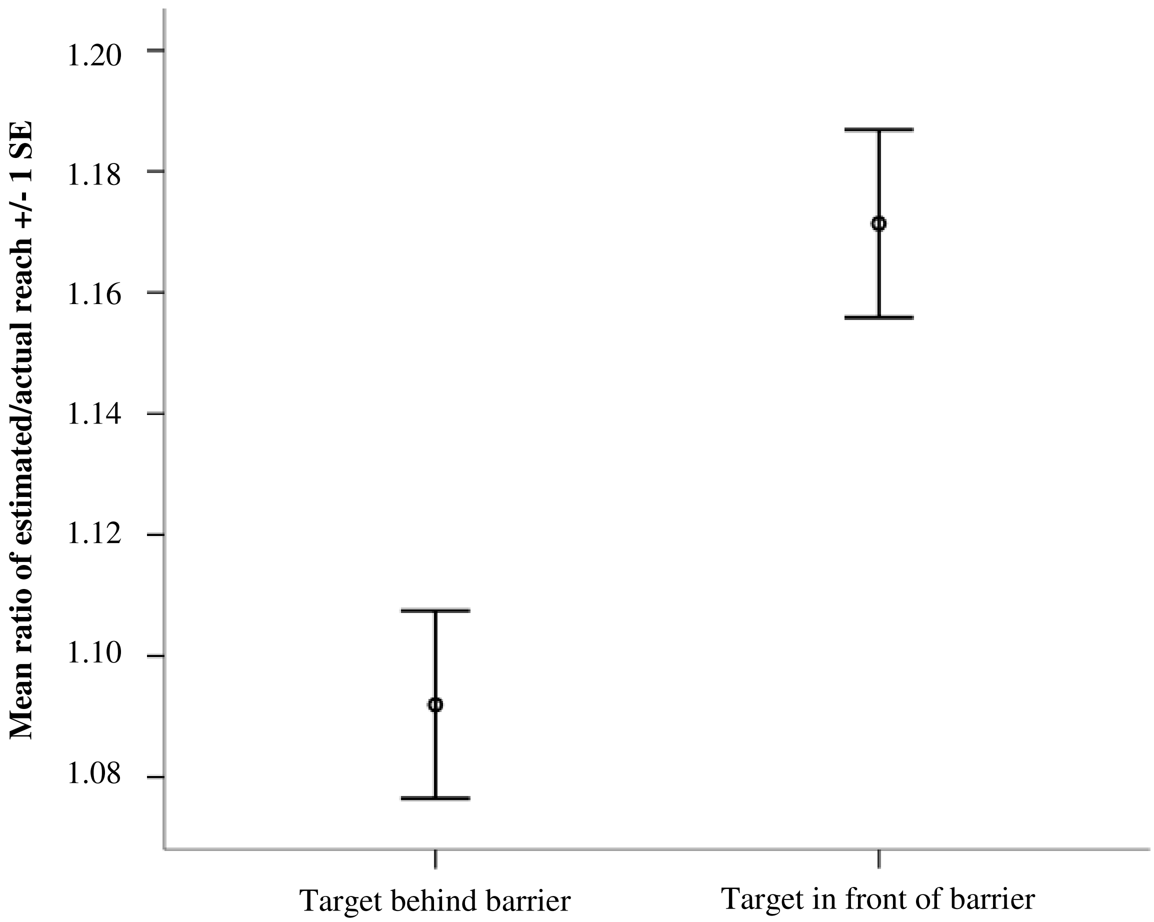

Figure 4. Mean ratios of estimated longest reach / actual reach as a function of the barrier conditions. Error bars represent +/- 1 SEM.

EXPERIMENT 2

Given the tentative results of Experiment 1, we are curious how environmental constraints such as a barrier may interact with constraining the body's capabilities for action more directly. Previous work has shown that constraining or enabling the body may influence distance perception in near space (e.g., Lessard et al. 2009, Witt et al. 2005) or even shrink the extent of perceived near space (Lourenco & Longo, 2009). Experiment 2 tested whether both environmental (barrier) and body constraints (arm weights, e.g., Lourenco & Longo, 2009) that limit reaching influence judgments of distances to reachable objects. We expected participants to judge distances as farther when the body or environment did not allow an observer to reach a target. While we expected a main effect for both the barrier and the arm weights, we could find one effect to be stronger than the other. For example, there could be an effect of the barrier when the dominant arm is free, but no difference for the barrier when the dominant arm is restrained.

Methods

Participants. Forty-eight University of Utah undergraduate students participated for class credit. All participants provided written informed consent and had normal or corrected to normal vision. Five participants were left-handed and 43 were right handed.

Stimuli and apparatus. The main stimuli and apparatus were identical to Experiment 1. Participants also wore a 0.45 kg (1 lb.) exercise wrist weight.

Design. A within-subjects design was used for barrier condition (in front of barrier and behind barrier), arm weight (dominant or nondominant hand) and for distances to target (10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70 cm from front edge of table). Participants saw each distance once in each condition for a total of 52 trials. The order of presentation of trials and order of weighted arm was randomized.

Procedure. Experiment 2 used a procedure similar to that of Experiment 1, with the addition of the arm weights and subsequent additional trials, a blindfold to limit viewing of the apparatus between trials, and only one distance match per trial. After briefing and training, the experimenter attached an arm weight to the participant's dominant or non-dominant hand and instructed him or her to move the arm to become accustomed to the weight. We placed the weight on the dominant or nondominant hand rather than have weight and no-weight conditions to reduce potential demand characteristics. Participants were always told to think about reaching with their dominant hand, so the weight should only affect judgments when on the dominant hand; the weight-on-the-nondominant-hand condition is effectively equivalent to a no-weight condition, but may reduce potential experimental demands or biases that could occur due to simply wearing a weight on the wrist. To ensure that the participants did not see the stimuli being moved between trials, participants wore a blindfold. The experimenter placed the blindfold after each trial and then removed it before each subsequent trial. After the reaching estimate, only one distance match was completed (pulling out tape measure). Additionally, the target was placed at the target distance and then barrier placed in front of or behind the target so that the target was always at the correct distance. The procedure was otherwise identical to that of Experiment 1. After the experiment, participants completed a written debriefing survey. The questions were:

What do you think we were studying today? What do you think was the purpose of the Plexiglas presented on the table? Do you think the Plexiglas affected your judgment of the distance to the target? If so, how? What do you think was the purpose of the wrist weights? Do you think the wrist weights affected your judgment of the distance to the target? If so, how? Did you use any strategies to make your decisions? What were they?

Results and Discussion

Participants' mean dominant arm length was 71.90 cm (*SD* = 6.67 cm) and mean actual longest reach was 35.95 cm (SD = 8.26 cm). Four participants were excluded, three for failing to follow instructions and one due to being an outlier two standard deviations from the mean. Forty-four participants are included in the analyses below. Due to missing data of the distance judgments (less than 1%) we used mean imputation to clean the data.

Analysis using distances. We performed a repeated measures analysis of variance (RMANOVA) with barrier condition (2 levels, in front or behind barrier), hand weight (2 levels, dominant or nondominant hand), and distance (13 levels) as within-subjects factors with arm-weighted condition order as a between-subjects factor, and while there was not a significant main effect for condition order, there was a marginally significant effect for the barrier condition ($F(1, 42) = 3.55$, $p = 0.066$, $\eta^2_p = 0.078$, MSE = 21.52) such that distance judgments were *smaller* when the target was behind the barrier (M =39.55, SE = 0.63) compared to when the target was in front of the barrier (M = 39.92, SE = 0.64) and a significant main effect for distance ($F(12, 504) = 1353.19$, $p < 0.001$, $\eta^2_p = 0.97$, MSE = 44.08) such that farther distances were judged as farther. There was also a significant interaction between the hand-weighted and hand-weighted condition order ($F(1, 42) = 10.49$, p =0.002, $\eta^2_p = 0.20$, MSE = 65.87). When participants' nondominant hands were weighted first, distances were judged to be greater when the left hand was weighted (*M* = 39.77, *SE* = 0.885) compared to when the right hand was weighted (*M* = 38.38, *SE* = 0.957), $F(1, 19) = 11.32$, $p = 0.003$, $\eta^2_p = 0.373$, MSE = 44.36. [1]

There was not a main effect of the barrier in the predicted direction for the analysis using the actual distances, unlike Experiment 1 and the findings of Morgado, Gentaz, Guinet, Osiurak, and Palluel-Germain (2012). Morgado et al. (2012) used a computer-based rather than hand-operated distance matching task, which could explain some of the discrepancy. The inaccurate target placement in Experiment 1 may also explain some of the discrepancy.

The lack of a main effect for the arm-weight condition across all distances is, while disconcerting, perhaps easily explained. The arm weight may simply have been too light to significantly affect judgments, or it may have only felt heavy enough towards the end of the condition when the arm was fatigued. While we made sure that the participant understood that she was supposed to think about reaching with her dominant hand at the beginning of the experiment and each block, we did not emphasize it during every trial (e.g., "Could you reach the target" rather than "Could you reach the target with your right [dominant] hand?"). A more consistent emphasis may have focused the participant's attention to the relevant hand. There is also the possibility that participants were judging the distance to the barrier instead of the target when the nondominant hand was weighted. The target was always at the same distance but the barrier was shifted by ~3 cm between the barrier conditions so that it

[1] Follow-up RMANOVAs were conducted to assess order effects (using the first weighted condition only) as well as handedness (excluding left handers). The results were the same as in the full analyses, showing a slight effect of the barrier to increase distance estimation in the direction opposite from what was predicted (greater estimates when the target was in front of the barrier). These results show no relevant theoretical implications. There were no gender effects.

would be farther away when the target was in front of the barrier and closer when the target was behind the barrier. Estimating to the barrier is consistent with the significant interaction between the hand-weight and barrier conditions such that judged distances were greater when the target was in front of the barrier (and the barrier was farther away) than when the target was behind the barrier (and the barrier was closer). This does beg the question of why participants would judge distances to the target when one hand was weighted and the barrier when the other hand was weighted. If participants were always judging distances to the barrier, it may imply an even stronger effect for the barrier.

<u>Analysis using ratios of estimated/actual distance.</u> As in the previous experiment, we were interested in examining distance judgments across reachable and unreachable spaces. We formed ratios of estimated/actual distance for each condition split by reachability for a participant's actual reach, as in our analyses in Experiment 1.

To test if distance judgments were different across reachable and unreachable space, we performed a RMANOVA with barrier condition (two levels, in front and behind), hand weighted (two levels, dominant and nondominant), and reachable space (two levels, reachable and unreachable) as within-subject factors and hand-weighted order as a between-subject factor. There was a significant main effect for reachable space ($F(1, 42) = 26.51$, $p < 0.001$, $\eta^2_p = 0.387$, MSE = 0.018, see Figure 5) such that there was a greater overestimation of distance judgments when the target was within reachable space ($M = 1.05$, $SE = 0.016$) than when the target was outside of reachable space ($M = 0.979$, $SE = 0.017$).

There were two important interactions that resulted when the distances were grouped as reachable or nonreachable. First, there was also a significant interaction between the hand-weighted and barrier conditions ($F(1, 42) = 22.32$, $p < 0.001$, $\eta^2_p = 0.258$, MSE = 0.002, see

Figure 6). Consistent with our hypothesis, when the dominant hand was weighted, participants judged distances to the target to be greater when the target was behind the barrier (M = 1.022, SE = 0.015) than when the target was in front of the barrier (M = 0.999, SE = 0.015), $F(1, 42) = 14.59$, $p < 0.001$, $\eta^2_p = 0.347$, MSE = 0.002. In the opposite direction, when the nondominant hand was weighted, participants judged distances to targets in front of the barrier (M = 1.030, SE = 0.016) to be greater than targets behind the barrier (M = 1.013, SE = 0.018). These results are consistent with the hypothesis that distances to be acted upon by one side of the body (dominant hand) will be scaled only when that side of the body (dominant hand) is impeded (by the barrier).

Second, the interaction between the barrier condition and reachable space was also significant, $F(1, 42) = 16.19$, $p < 0.001$, $\eta^2_p = 0.278$, MSE = 0.003, see Figure 7. When distances to the target were within reach, distances behind the barrier (M = 1.065, SE = 0.018) were judged greater than distances in front of the barrier (M = 1.040, SE = 0.016), $F(1, 42) = 6.380$, $p = 0.015$, $\eta^2_p = 0.132$, MSE = 0.004. When distances to the target were outside of reach, distances in front of the barrier (M = 0.989, SE = 0.018) were judged to be greater than distances in front of the barrier (M = 0.970, SE = 0.017), $F(1, 42) = 12.60$, $p < 0.001$, $\eta^2_p = 0.231$, MSE = 0.001. Consistent with our hypothesis, the barrier scaled only action-relevant, reachable spaces (while there was a significant effect for unreachable spaces, it was in the opposite direction of our predictions).

Looking at the data split by reachability, the lack of main effect for the barrier is likely because of the large effect in the opposite direction for targets outside of reachable distance. When targets were outside of reachable distance, targets in front of the barrier looked farther than targets behind the barrier. This likely canceled out the effect of the barrier over reachable distances. The analysis using the distance ratios (estimated distance/actual distance) appears to be a more sensitive measure as the ratios compensate for the different reachable (shorter) and unreachable (longer) distances so that we are measuring the relative over- or underestimation; with the ratios we can compare across all distances more evenly. Additionally, the use of the ratios allows us to collapse the data for reachable and unreachable distances, making the 13-item variable distance into two that are more easily and theoretically soundly compared.

There was a significant three-way interaction between barrier condition, hand-weighted condition, and reachable space, $F(1, 42) = 17.39$, $p < 0.001$, $\eta^2_p = 0.293$, MSE = 0.002, see Figure 8. When the dominant hand was weighted and the target was within reachable space, distances were judged to be greater when the target was behind the barrier ($M = 1.076$, $SE = 0.017$) compared to when the target was in front of the barrier ($M = 1.013$, $SE = 0.017$), $F(1, 42) = 34.20$, $p < 0.001$, $\eta^2_p = 0.449$, MSE = 0.003. When the dominant hand was weighted and the target was outside reachable space, distances were judged greater when the target was in front of the barrier ($M = 0.986$, $SE = 0.017$) compared to when the target was behind the barrier ($M = 0.968$, $SE = 0.017$), $F(1, 42) = 10.09$, $p = 0.003$, $\eta^2_p = 0.194$, MSE = 0.001.

Within the ratio analysis, we predicted main effects of both the barrier and the hand-weighted condition, but these effects were not significant. Again we attribute this to the differential effects over reachable and unreachable distances. Consistent with our hypothesis and previous research (e.g., Lessard, Linkenauger, Proffitt, 2009), unactionable (unreachable) distances were not scaled, while actionable (reachable) distances were scaled when action (reaching) relevant capabilities were changed. When considered in light of the interaction between reachable distances and the action manipulations, both environmental and body-based ability modifiers influenced the perception of relevant distances, and interacted so that reachable distances were reported as greater when both modifiers were present (M = 1.076, SE = 0.017) compared to when only one modifier was present (in front of barrier, dominant hand weighted: M = 1.013, SE = 0.017; behind barrier, nondominant hand weighted: M = 1.054, SE = 0.020).

Reaching affordance judgments. Reaching judgment crossover point ratios were calculated in the same manner as Experiment 1. To test these reaching judgments, we performed a paired-samples t-test comparing the crossover point when the target was in front of the barrier (M = 1.22, SD = 0.26) to the crossover point when the target was behind the barrier (M = 1.21, SD = 0.26); t (43) = 0.443, p = 0.660. We also performed a paired-samples t-test comparing the crossover point when the dominant hand was weighted (M = 1.22, SD = 0.28) to the crossover point when the nondominant hand was weighted (M = 1.21, SD = 0.26); t (43) = 0.751, p = 0.457. Since our hypothesis predicted the greatest difference when the dominant hand was weighted and the target was behind the barrier compared to when the nondominant hand was weighted and the target was in front of the barrier, we also tested these conditions. We performed a paired-samples t-test comparing the crossover point when the dominant hand was weighted and target was behind the barrier (M = 1.23, SD = 0.28) to the crossover point when the nondominant hand was weighted and target was in front of the barrier (M = 1.21, SD = 0.27); t (43) = 0.825, p = 0.414. In no cases were the reaching judgments significantly different; participants judged that they could reach the same distance in all conditions.

Debriefing question analysis. Previous research has argued that changes in perception of the environment based on experimental changes to the body are due to experimental demand (Durgin, Klein, Spiegel, Strawser, & Williams, 2012). We used the debriefing questions presented after the study to assess task demand. Durgin et al (2012) also used an extensive debriefing to assess task demand. They divided their responses to the question "Why do you think you were asked to wear the backpack?" into three categories: the purpose was to increase perceived slant, the purpose was to alter perceived slant, and other. Before asking participants about the purpose of a task, we asked the more generic question, "What do you think we were studying today?" Prompting about a specific task may present an experimental demand of its own; if a debriefing question asks about a certain task, a participant can logically conclude that the experimenter intended an experimental manipulation to have an effect, so all participants should predict an effect, even if they do not know what it was. For this reason, we coded our responses to this question using different categories: other/unrelated, generic unspecified effect (e.g., "distance perception"), a manipulation would have an unspecified effect (e.g., "if you can judge distance better with a weight on your wrist,"), or a manipulation would have a specified effect (e.g., "perception of how far you can reach and how it changes if the hand you are reaching with is weighted down"). Most participants (26/44) guessed a generic unspecified effect, 8/44 participants guessed a manipulation would have an unspecified effect, 7/44 guessed a specified effect, and 3/44 guessed something unrelated. See the Appendix for a complete list of responses to this question.

To see if there was a difference in the experimental effect for participants who guessed a specified effect and those who did not, we performed a RMANOVA with hand-weighted (two levels, dominant and nondominant), barrier condition (two levels, in front and behind), and reachable space (two levels, reachable and unreachable) as within-subject factors and hand-weighted order and subject naivety (unrelated and generic effect, N=29 versus manipulation effect and specified effect, N=15) as a between-subjects factor for the participants in the two "specified effects" categories using the distance ratios. There was not a significant main effect for participant naivety ($F(1, 40) = 0.480$, $p = 0.493$, $\eta^2_p = 0.012$, MSE = 0.81). However, naivety was part of a significant interaction between the hand-weighted condition, barrier condition, and naivety ($F(1, 40) = 10.087$, $p = 0.003$, $\eta^2_p = 0.201$, MSE = 0.001). Contrary to our hypothesis, naïve participants, when the nondominant hand was weighted, judged distances in front of the barrier ($M = 1.033$, $SE = 0.17$) as longer than when behind the barrier ($M = 1.003$, $SE = 0.19$), $F(1, 27) = 7.995$, $p = 9\ .009$, $\eta^2_p = 0.228$, MSE = 0.003. Participants who even vaguely guessed the purpose of the experiment did not otherwise have significantly different distance judgments from naïve participants, indicating that either experimental demand was low or knowledgeable participants did not actively try to fulfill the experimenters' hypotheses.

In response to the question, "What do you think was the purpose of the Plexiglas presented on the table?" 13 participants responded that the purpose of the barrier was to make distances appear farther or closer. Performing a RMANOVA with hand-weighted (two levels, dominant and nondominant), barrier condition (two levels, in front and behind), and reachable distance (two levels, reachable and unreachable) as within subject factors and hand-weighted order and naivety of this question (generic effect, $N = 31$ versus distance-specific effect, $N = 13$) as between-subject factors showed no significant main effects, but did show a significant interaction between naivety, hand-weighted condition, and barrier condition ($F(1, 40) = 4.179$, $p = 0.048$, $\eta^2_p = 0.095$, MSE = 0.001). Contrary to our hypothesis, naïve participants judged targets in front of the barrier as closer when the dominant hand was weighted ($M = 0.986$, $SE = 0.25$) than when the nondominant hand was weighted ($M = 1.020$, $SE = 0.19$), ($F(1, 29) =12.85$, $p < 0.001$, $\eta^2_p = 0.307$, MSE = 0.004). There was also an interaction between hand-weighted condition, barrier condition, reachable space, and naivety ($F(1, 40) = 4.195$, $p = 0.047$, $\eta^2_p = 0.095$, MSE = 0.002). Naïve participants judged distances within reachable space in front of the barrier as greater when their nondominant hand was weighted ($M = 1.06$, $SE = 0.13$) than when their dominant hand was weighted ($M = 0.988$, $SE = 0.10$), $F(1, 29) = 19.15$, $p < 0.001$, $\eta^2_p = 0.398$, MSE = 0.004, contrary to our hypothesis. Participant naivety of the barrier-related hypothesis did not seem to unduly impact distance judgments in favor of our hypothesis.

In response to the question, “Do you think the Plexiglas affected your judgment of the distance to the target? If so, how?” 25 participants responded that yes or maybe the barrier affected their distance judgments. Performing a RMANOVA with hand-weighted (two levels, dominant and nondominant), barrier condition (two levels, in front and behind), and reachable space (two levels, reachable and unreachable) as within-subject factors and hand-weighted order and self-described influence of effect (yes/maybe ($N = 25$) versus no ($N = 19$) revealed a significant interaction between barrier condition and influence, $F(1, 40) = 8.313$, $p =0.006$, $\eta^2_p = 0.172$, MSE = 0.003. Participants self-reporting as being influenced by the barrier judged distances in front of the barrier ($M = 1.022$, $SE = 0.23$) as smaller than distances behind the barrier ($M = 1.040$, $SE = 0.023$), $F(1, 23) = 8.074$, $p =0.009$, $\eta^2_p = 0.260$, MSE = 0.002. Participants who said they were influenced by the barrier actually did estimate distances behind the barrier as greater, suggesting that there may be some self-awareness of changes in perception.

In response to the question, “What do you think was the purpose of the wrist weights?” only two participants said that the purpose was to increase or decrease distance judgments. Twenty participants said that the purpose was to change perceived reach. In response to the question, “Do you think the arm restraints affected your judgment of the distance to the target? If so, how?” eleven participants responded yes or maybe.

In response to the question, “Did you use any strategies to make your decisions? What were they?” no participants responded that they tried to fulfill the experimental hypotheses. If anything, participants actively worked against it with responses such as “I tried to stop the measuring tape at a shorter distance than what I actually thought it was,” “I ignore the plexigass,” and “use my off arm as a measurement tool to determine how far away the target was.” Given responses such as these, we are skeptical that participants were unduly influenced by experimental task demands.

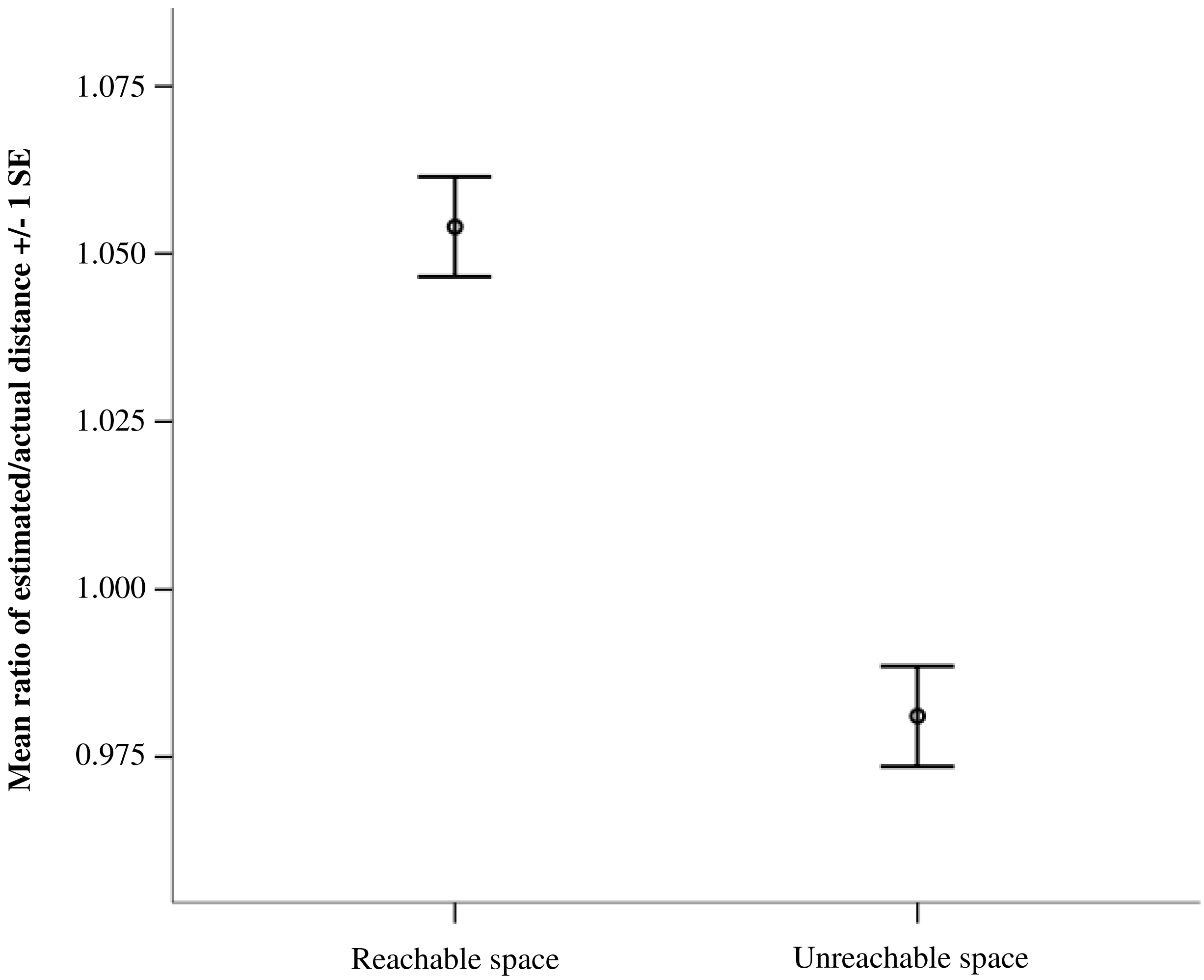

Figure 5. Experiment 2: Mean ratios of estimated distance judgments / actual distances as a function of reachable space. Error bars represent +/- 1 SEM.

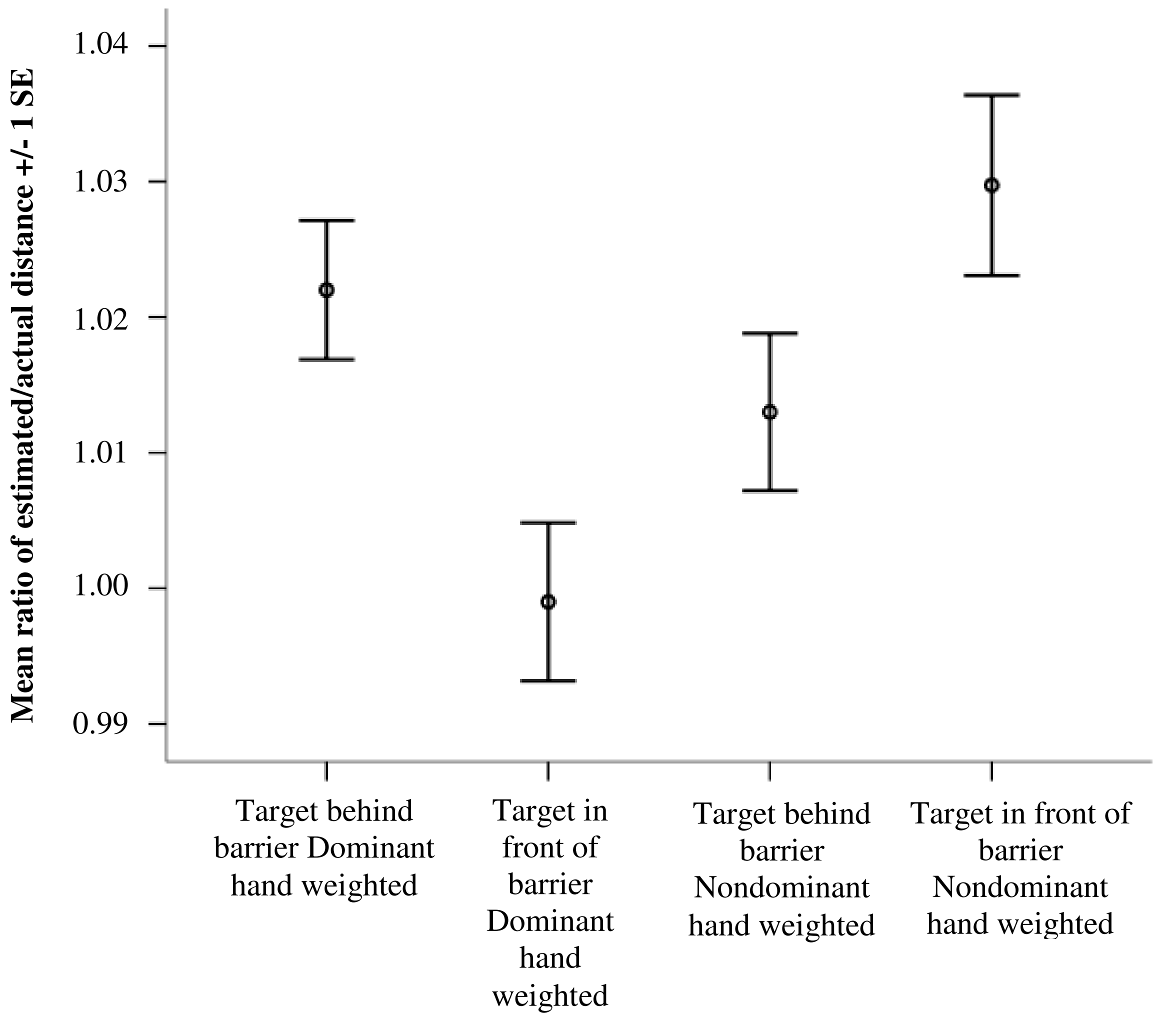

Figure 6. Experiment 2: Mean ratios of estimated distance judgments / actual distances as a function of the barrier and hand-weighted conditions. Error bars represent +/- 1 SEM.

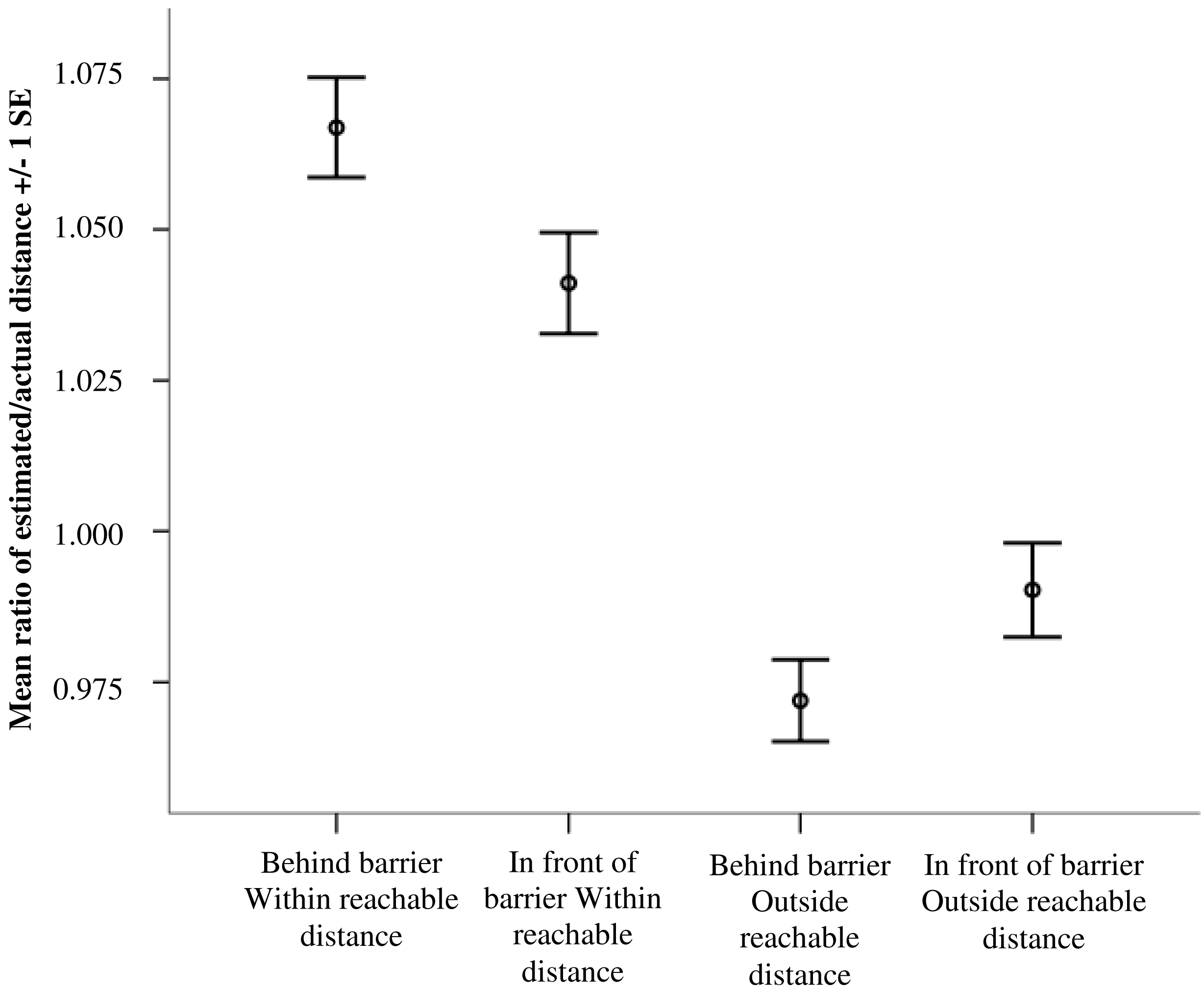

Figure 7. Experiment 2: Mean ratios of estimated distance judgments / actual distances split between reachable and unreachable spaces as a function of the barrier conditions. Error bars represent +/- 1 SEM.

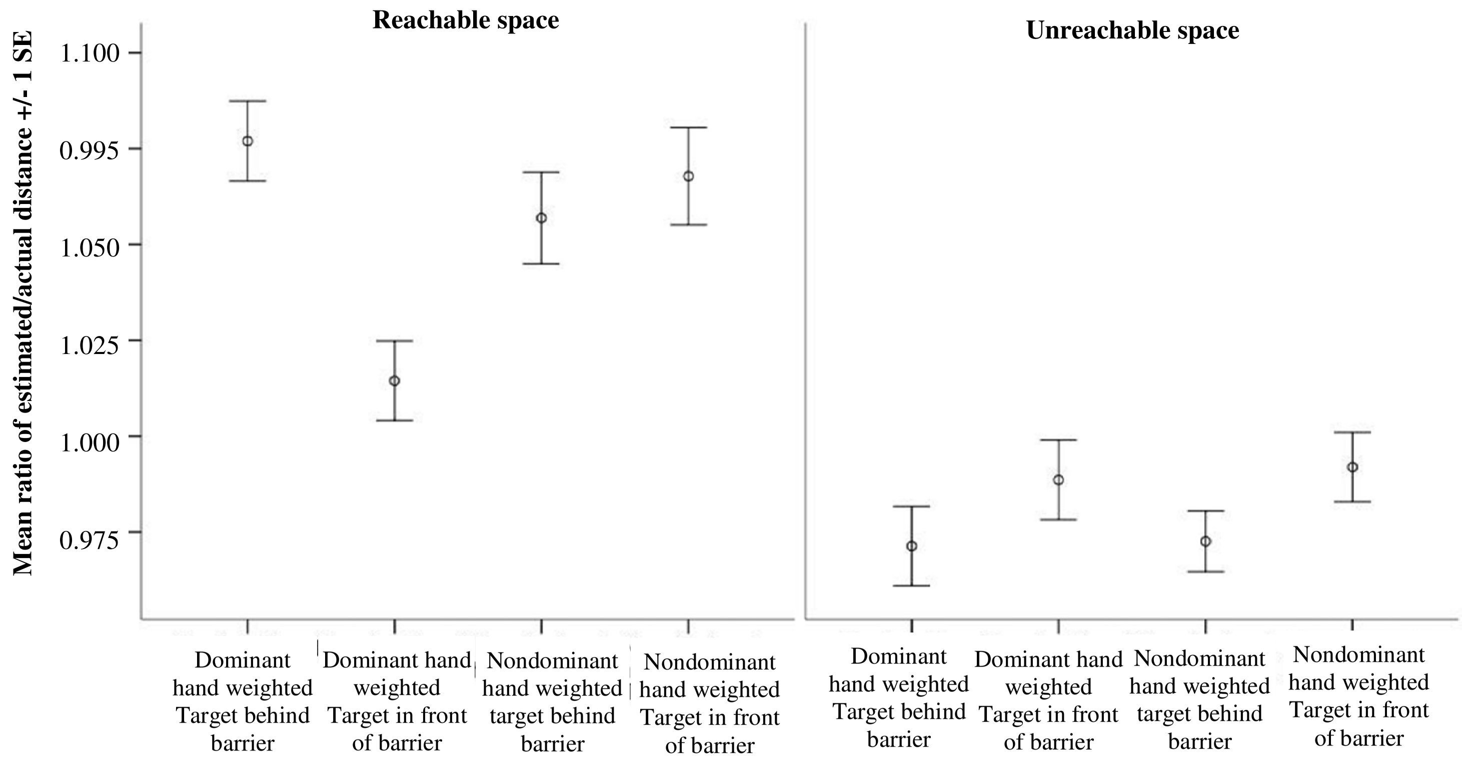

Figure 8. Experiment 1: Mean ratios of estimated distance judgments / actual distances split between reachable and unreachable spaces as a function of the barrier and hand-weighted conditions. Error bars represent +/- 1 SEM.

GENERAL DISCUSSION

In Experiment 2, participants were asked to estimate their reach and the distance to a target while the target was in front of or behind a barrier and the participants' dominant (reaching) hand or nondominant hand was weighted. The effects of both the barrier and weighted arm were found only when the distances measured were split into reachable and unreachable spaces. Action-relevant spaces were scaled based on the affordances allowed to the participant based on both the environment's facility for action and the participant's action capabilities.

In Experiment 1, there was a significant difference between reachability judgments when the target was in front or behind the barrier, but this difference was not evident in Experiment 2. The weights and barrier conditions together may have impeded or confused judgments, or this result may be a remnant of the incorrect target placement in Experiment 1; with the correct target placement, there may not have been a difference in affordance judgments. Right-handers usually judge their right arm and reach as greater than their left arm and reach (Linkenauger, Witt, Stefanucci, Bakdash, & Proffitt, 2009). Since there was no difference in affordance judgments between the two hand-weighted conditions, it is unlikely that participants were thinking of reaching with their unweighted hand; it is more likely that participants thought of reaching with the same hand in all conditions but that the ability manipulations were not strong enough to influence judgments for distances that were

5 cm apart. The difference in affordance judgments may be smaller than 5 cm, which could be lost between measurements, or a heavier hand weight could be employed.

The debriefing results were mixed. When we asked participants general questions, they did not explicate that we were studying the effects of constraints on distance perception, but were more likely to predict our hypotheses when asked more specific, possibly leading questions. Of those who predicted the experimental hypothesis, a few reported that they actively compensated or worked against our hypotheses, so we question arguments that the effects of this experiment are created by task demands – if anything, the effects of this experiment were found in spite of task demands. Future researchers should word debriefing questions carefully to control for experimental task demands, and avoid the experimental demands of the questions.

This study provides evidence supporting the dual etiology of affordances - environment and actor's ability – and the idea that people perceive the world differently depending on those affordances. It shows that the effect of affordances on perception of spatial layout is mediated by an interaction between these two factors.

This study still does not identify the mechanisms involved in scaling distance judgments based on affordances. Motor simulation is a possible mechanism; participants may internally simulate the motor action necessary to perform a task to judge the distance to it (Wiit & Proffitt, 2008). The barrier or hand weights could impede or change simulation. While we are skeptical that demand characteristics or task expectation played a large role in the results, we cannot completely rule them out as possible cause. Future research should carefully compose debriefing questions. We should also work towards a less ambiguous measure of reaching ability and distances than self-reported judgments.

While previous research and theory suggest that weighting the arms influences perception of space (Lourenco & Longo, 2009), this was not unambiguously shown here; future research should explicitly test the effect of arm weights on distance judgments when the barrier is not present. Future research should also use smaller intervals between distances or multiple trials at each distance to better identify the cross between judged reachable and unreachable distance.

While this study shows an interaction between environmental affordances (the barrier) and body-based affordances (the arm weights), future research will be needed to determine to what degree they interact and if one is more important than the other.

CONCLUSION

Changing the affordances allowed in an environment has been demonstrated via changes to the body and changes to the environment. These studies integrate the two parts of affordances to explore how they interact. When distances are within actionable space, changing the action-relevant abilities of the body and actions allowed by the environment scales judgments of those distances. These studies do not definitively describe the degree of interaction between body and environmental affordances, but suggest that future research consider the specific environment in addition to the body.

APPENDIX

Responses to Experiment 2 debriefing question “What do you think we were studying today?” Spelling and grammar unchanged from original responses.

Generic unspecified effect

- Distance perception
- Depth perception
- Distance perception
- Visual percecption
- Distance perception
- How people judge distances
- Distance perception
- Depth perception
- Perception
- How well you can tell how far away things are.
- Interpersonal distance perception
- Perceiving length.
- Depth perception
- Visual perception and how we can determine the distance
- Perception with changes in the environment.

- Distance perception
- Visual Perception
- Judgement of distance to the target. and judgement of the distance measured.
- I think you were studying how well we perceived our arms when we had something that allows us to notice our arms.
- Depth perception
- Depth perception
- How well I am able to judge spacial distances.
- My perception of how far I could reach an object.
- Depth perception
- The ability to percieve depth and perception
- Depth perception

A manipulation would have an unspecified effect

- Perception of reach to an object. vs the actual distance of reach between me and the object
- If you can judge distance better with a wieght on your wrist
- People's perception on their reach, and how accurate they can estimate length
- I think that you were studying how well we measured space when we had the extra weight.
- Visual perception and how the weight affected perception.
- How we perceive things if the barrier was in front of us
- Perception of distance with interfering stimuli

A manipulation would have a specified effect

- I think that they were studying weather or not a certain amount of wieght on the body changed my perception about how far an object actually is away from me.
- Perception of how far you can reach and how it changes if the hand you are reaching with is weighted down.
- Our perception of distance in relation to how far away something is and what our perception of our ability to reach it is, versus the distance something actually is
- How we perceive distances based on visual references and how the arm becoming tired effects our judgement of distances
- I think you were studying our perception between when the plastic was in front of the dot and behind the dot; maybe to see if there was a consistency.
- How far we thought the object was away from me and if I thought that I could reach the object.
- Whether or not putting a weight on a different part of the body will affect our perception of being able to tell distance and if we can touch something in front of us.

<u>Other</u>

- How the brain measures things
- It was interesting.
- It was interesting to see how far I could actually reach. I thought I could reach a lot farther then I did

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